Experimental Investigation of Laser Sintering Process on CL91RW Material

"Effect of layer thickness and part orientation on quality of fabricated parts."

[1]Falgun S Jani, [2]Vidya Nair,
[1],M.E scholar, [2]Assistant Professor,
Department of Mechanical Engineering,
LDRP Institute of Technology and Research, Gandhinagar, Gujarat, India

---

***Abstract* - Compared with conventional material removal manufacturing technologies, rapid prototyping is a layer-based material addition process and can produce a 3-D freeform object with a CAD-defined geometric model directly. Due to their comparatively high rapidity and flexibility, however, they have also been used in various manufacturing and nonmanufacturing applications. This process is highly influenced by powder and laser parameters such as laser power, scan rate, spot size and layer thickness. The aim of this research is to improve the performance of the SLS process by optimizing the control of process parameters that have very strong influence on the quality of the built part. Therefore a study on fabricating a part with CL91RW powder has been performed by selective laser sintering on process parameter Orientation and layer thickness.In order to determine critical states of the sintering parameters, analysis of variances has applied while optimization of the parameters affecting the surface quality and dimension accuracy were investigated.**

***Keywords* - Selective laser sintering; Optimization, Roughness, Rapid Prototyping, Rapid Manufacturing, ANOVA**

I. Introduction

The manufacturing industry is always searching for ways to enhance production with reducing cost. Conventional material removing manufacturing technologies such as ,milling, tapping, turning, etc. create 3Dimensional physical parts by removing material using cutting tools. One major demerit is the dependent on the manufacturing complexity [1]. The Additive Manufacturing (AM) field is growing rapidly since two decades . The technological advances made in this field are pushing its application from prototype building to production of real parts [2]. The "selective laser sintering" (sls) process was first use at the University of Texas at Austin & then after commercialized by DTM corporation (U.S.) [4]. There are many new technologies have been introduced and it is use in many industries in several sectors. So it is new technology.

In SLS process whole construction chamber is divided in two parts. One is distribution chamber and building chamber. As the process start building plat form move down ward side. At the same time deposit platform move upward. and distributor move left to right and spread layer over the last layers. Powder is melt by the action of laser that create complete fusion of layer to the last one .The part of powder of model slice is fused and the other powder remain loose and can be recycled.

II. Experiment

A).Experimental setup

The experiments have done on the Selective laser sintering machine (CONCEPT Laser GmbH **M1** the Hofmann Innovation Group AG). The specification of the machine is shown in the table 1. The actual experimental setup is as shown in fig. 1 the powder used in this study was Fe-Ni-Cr powder with particle size of 20 μm and the chemical composition is given in Table 2.

Table 1 Laser sintering machine specification

Model	Specification
Build envelope	250 x 250 x 250 mm (x, y, z)
Layer thickness	20 - 80 µm
Production speed	2 – 10 cm3/h (depending on material)
Max. scanning speed	7 m/s
Focus diameter	70 – 200 µm
Laser system Fiber laser	200 W (cw)
Laser source	Nd:Yag

Fig 1 Experimental setup

Table 2 Chemical composition of CL91RW powder

Fe	c	Ni	Cr	Al	Si	Mn	Mo
Bal.	0.03	9.2	12	1.6	0.3	0.3	1.4

B.) Factors influencing the selective laser sintering process

There are mainly two types of factor that affect any process one is the controlled and another is uncontrolled one. Here in the SLS, the controlled factors are laser power, scan rate, spot size and layer thickness. etc. The uncontrolled factors are that factors which can't be controlled during process. In this paper, the uncontrolled factors were neglected and controlled factors were selected for study. It has noted that affecting parameters were layer thickness and orientation . Here all two factors were considered. Each of the factors with three levels has taken as shown in table 3.

Table 3 factors and their levels.

No	Factor	Description	Level 1	Level 2	Level 3
1	Layer thickness	A	30	50	70
2	Orientation	B	0	45	90

C.) Methodology

In this research work the sprue puller pin (fig 2) has manufactured. The specimen selected for the experiment is CL91RW material. Total 9 run have identified after applying design of experiment with 2 input parameters and 3 levels. Here the Pin diameter has measured by CMM machine as one output parameter and surface roughness has measured by surface roughness taster. Analysis of variance (ANOVA) has used to identify significant effect of parameters and regression analysis have to follow to optimize parameter values.

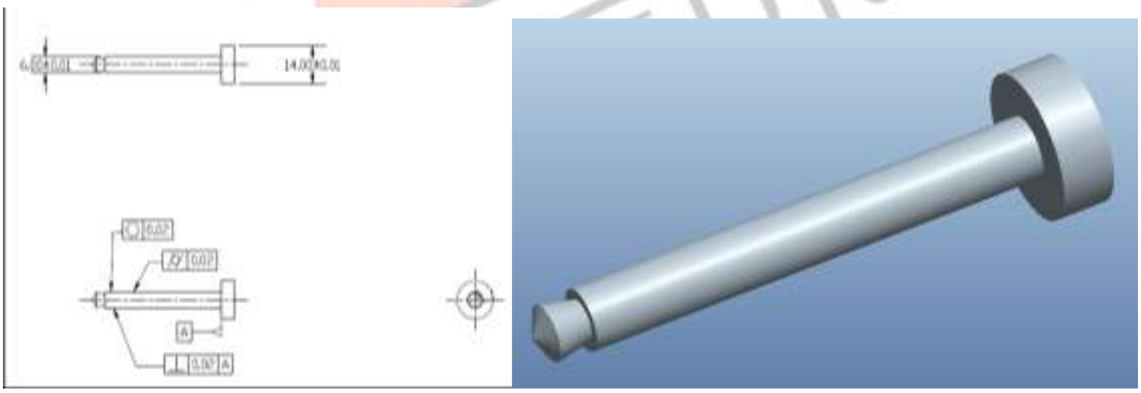

Figure 2. Cad Model and 2-D drawing

Figure 3.Part fabricated by SLS Process

III. RESULT AND DISCUSSION

Total 9 run have been carried out with 2 input parameters and 3 levels. Here the Pin diameter (Ø6.0000mm) has measured by CMM machine as one output parameter and surface roughness has measured by surface roughness taster.

Table 3: Design matrix and measured experimental results.

Run	Factor 1 A:Layer Thickness µm	Factor 2 B:Orientation Degree	Response 2 Diameter 1 mm	Response 3 Surface Roughness Ra (µm)
1	30	0	6.0702	9.9000
2	30	45	6.0998	6.7000
3	30	90	6.1148	5.7000
4	50	0	6.1378	13.1000
5	50	45	6.1301	12.8000
6	50	90	6.1403	10.0000
7	70	0	6.1895	17.7000
8	70	45	6.1588	17.4000
9	70	90	6.1609	12.3000

A).Analysis of Variance (ANOVA) for Diameter 1

The results of analysis of variance (ANOVA) for *Diameter 1* of SLS are shown in Table 4. A low P-value (≤0.05) indicates statistical significance for the source on the corresponding response (i.e., $\alpha = 0.05$, or 95% confidence level), this indicates that the obtained models are considered to be statistically significant, which is desirable; as it demonstrates that the terms in the model have a significant effect on the response

Final Equation: =

$$\text{Diameter1 } (\text{Ø}6.0000 \text{ mm}) = + 6.14 + 0.031 * A + 9.767E\text{-}003 * B - 8.400E\text{-}003 * A * B - 0.010 * A - 6.667E\text{-}004 * B^2$$

Table 4: Analysis of variance.

Source	Sum of square	df	Mean Square	F Value	p-value Prob > F	
Model	0.00675402	5	0.001350804	13.61	0.0284	**Significant**
A-LAYER THICKNESS	0.00569184	1	0.00569184	57.34	0.0048	
B-ORIENTATION	0.00057233	1	0.000572327	5.77	0.0958	
AB	0.00028224	1	0.00028224	2.84	0.1904	
A^2	0.00020672	1	0.000206722	2.08	0.2447	
B^2	8.8889E-07	1	8.88889E-07	0.01	0.9306	
Residual	0.00029782	3	9.92726E-05			
Cor Total	0.00705184	8				

The Model F-value of 13.61 implies the model is significant. There is only a 2.84% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant.In this case A are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Std. Dev. 9.964E-003,R-Squared0.9578, Mean 6.13, Adj R-Squared 0.8874, C.V. % 0.16,Pred R-Squared 0.5443, PRESS 3.214E-003, Adeq Precision 9.973.The "Pred R-Squared" of 0.5443 is not as close to the "Adj R-Squared" of 0.8874 as one might normally expect. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response tranformation, outliers, etc."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable.Your ratio of 9.973 indicates an adequate signal. This model can be used to navigate the design space.

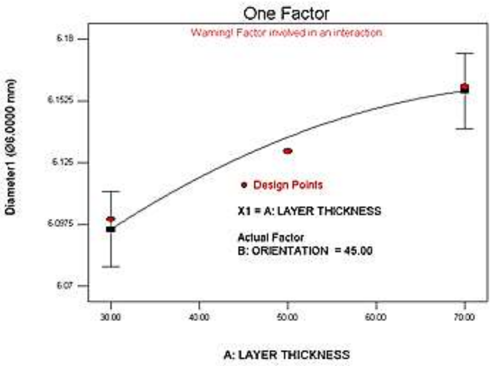

Fig 4 (a): One factor Effect –Layer Thickness

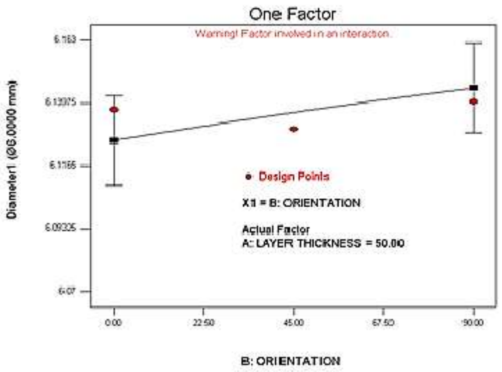

Fig 4 (b): One factor Effect – Orentation

Fig. 4(a-b) has shown individual effect of Layer Thickness and Orientation. Referring to table 4, Layer thickness has identified as most significant parameter with highest value of ‘F’ is 57.34.

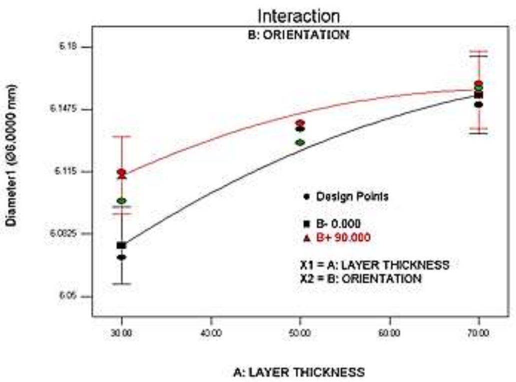

Fig 5 : Interactive factor Effect

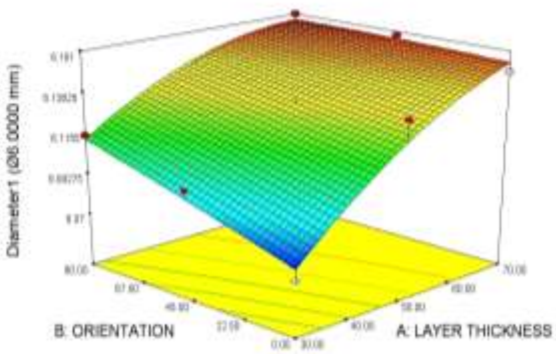

Fig 6 : 3D Interactive factor Effect

Fig. 5 shows that interaction effect of Layer Thickness and Orientation. which clearly concluded that as layer thickness is increases and Orientation increases the dimension accuracy is decreases suddenly.

Fig. 6 has shown 3D interaction effect of significant interactive parameters shown in fig 5. Fig. 7 exhibits the relationship between the actual and predicted values of surface roughness . These figures also indicate that the developed models are adequate and predicted results are in good agreement with experimental data.

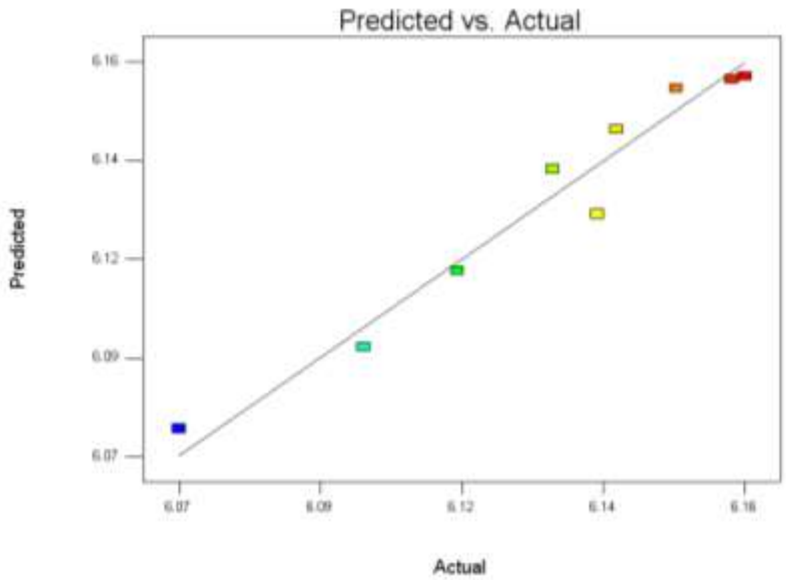

Fig: 7 Graph of actual vs predicted values.

B.)Analysis of Variance (ANOVA) for Surface Roughness

The results of analysis of variance (ANOVA) for Surface *Roughness* of SLS are shown in Table 4. A low P-value (≤0.05) indicates statistical significance for the source on the corresponding response (i.e., α = 0.05, or 95% confidence level), this indicates that the obtained models are considered to be statistically significant, which is desirable; as it demonstrates that the terms in the model have a significant effect on the response.

Final Equation: =

$$Roughness = + 12.53 + 4.18 * A - 2.12 * B - 0.30 * A * B - 0.35 * A^2 - 0.85 * B^2$$

Table 5: Analysis of variance.

Source	Sum of square	df	Mean Square	F Value	p-value Prob > F	
Model	133.9333333	5	26.79	15.43	0.0238	**Significan**
A-LAYER THICKNESS	105.0016667	1	105.00	60.50	0.0044	
B-ORIENTATION	26.88	1	26.88	15.49	0.0292	
AB	0.36	1	0.36	0.21	0.6797	
A^2	0.245	1	0.245	0.14	0.7321	
B^2	1.445	1	1.445	0.83	0.4288	
Residual	5.206666667	3	1.7355556			
Cor Total	139.14	8				

The Model F-value of 15.43 implies the model is significant. There is only a 2.38% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.Std. Dev. 1.32, R-Squared 0.9626, Mean 11.73, Adj R-Squared 0.9002, C.V. % 11.23, Pred R-Squared 0.5493, PRESS 62.72 ,Adeq Precision 11.714.The "Pred R-Squared" of 0.5493 is not as close to the "Adj R-Squared" of 0.9002 as one might normally expect. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response tranformation, outliers, etc. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable.Your ratio of 11.714 indicates an adequate signal. This model can be used to navigate the design space.

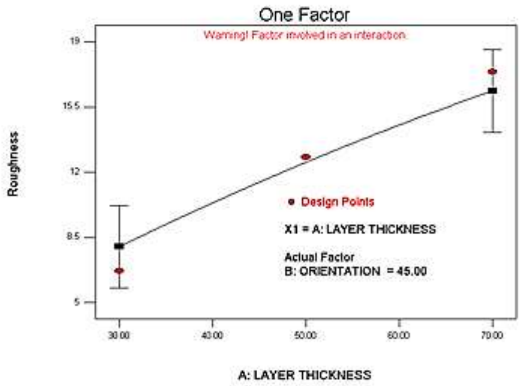

Fig 8 (a): One factor Effect –Layer Thickness

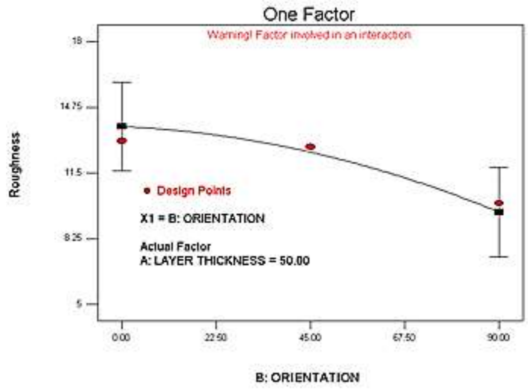

Fig 8 (b): One factor Effect – Orentation

Fig. 8 (a-b) has shown individual effect of Layer Thickness and Orentation. Referring to table 5, amplitude has identified as most significant parameter with highest value of 'F' is 60.50

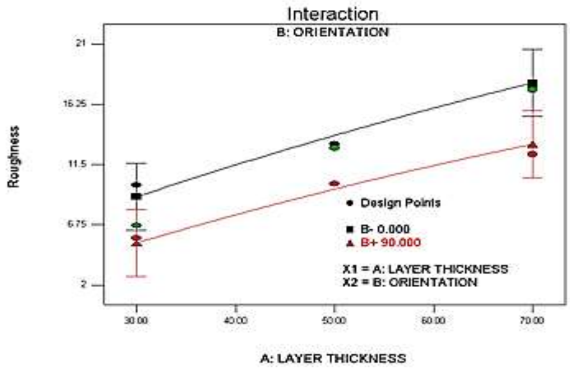

Fig 9 : Interactive factor Effect

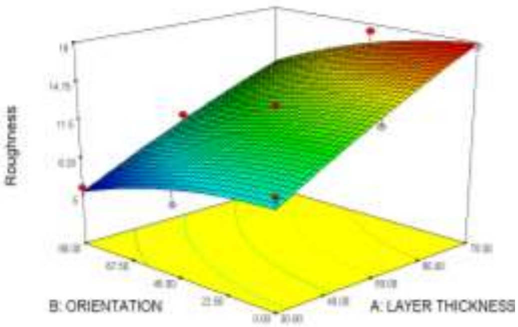

Fig 10 : 3D Interactive factor Effect

Fig. 9 shows that interaction effect of Layer Thickness and Orientation. which clearly concluded that as layer thickness is increases and Orientation decreases Surface roughness is decreases suddenly.

Fig. 10 has shown 3D interaction effect of significant interactive parameters shown in fig 9. Fig. 11 exhibits the relationship between the actual and predicted values of surface roughness . These figures also indicate that the developed models are adequate and predicted results are in good agreement with experimental data.

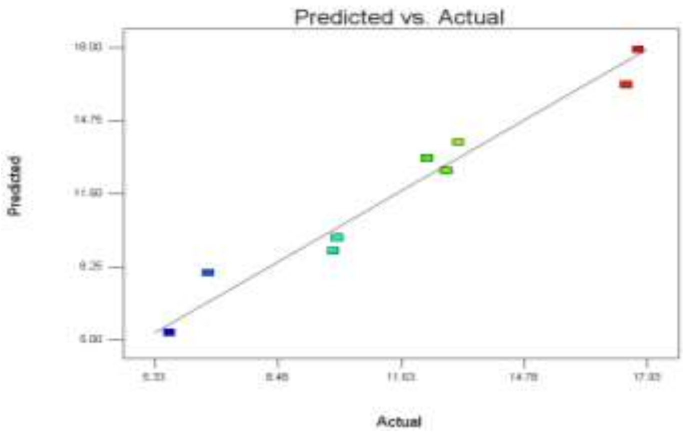

Fig: 11 Graph of actual vs predicted values.

IV. CONCLUSION

In the present paper, experimental investigation of laser sintering process parameter optimization has been performed on CL 91 RW as hot work steel material. The following conclusions can be drawn from the experimental investigation carried out within the factor range considered in this study.

(1) In this study, a second order mathematical model using anova has revalidated to predict the dimension of pin produced by SLS. From the results, it was found that the pin dimension mainly depends on value of Layer thickness and then on amount of Orientations .As we can see as the layer thickness increases the diameter is also increases. When layer thickness is increased, the energy input to make connection with under layer will be increased and consequently particles around laser beam are melt and line width increase. Optimized Pin dia has observed to be at 30 micron Layer thickness and 0 degree 6.0702mm.

(2) From the results, it was found that the roughness mainly depends on value of Layer thickness and then on amount of Orientations .As we can see as the layer thickness increases the surface roughness is also increases. Optimized Pin dia has observed to be at 30 micron Layer thickness and 90 degree is 5.700 micron.

Outcomes of present study have been useful to select optimal selective laser sintering condition, at which the Pin dimensions can achieve to improve quality of manufacturing part and surface roughness .

REFERENCES

[1] Process Parameter Optimization for Direct Metal Laser Sintering (DMLS) BY NingYu (2005)

[2] Wohlers T. Additive manufacturing state of the industry. Annual worldwide progress report, 2010, Wohlers Associates Inc., Fort Collins Co., 2010

[3] .MIRCEA ANCĂU & CRISTIAN CAIZAR, The Optimization of Surface Quality in Rapid Prototyping WSEAS International Conference on ENGINEERING MECHANICS, STRUCTURES, ENGINEERING GEOLOGY (EMESEG '08), Heraklion, Crete Island, Greece, July 22-24, 2008

[4] Mr. Chetankumar M.Patel1 Sandip.B.Patel2, Mit K.Shah, Experimental Investigation of Mechanical Properties and Surface Roughness of CL50WS Material Parts Made by Selective Laser Sintering Process, IJSRD - International Journal for Scientific Research & Development| Vol. 3, Issue 05, 2015,306-310

[5] Detailed report on Laser Cusing,) visited and downloaded.pdf, September2014,http://www.femeval.es/ proyectos /karma /Documents/D1%202 %20Materials%20datasheets%20%208%2010.pdf

[6] Byeong-Don Joo, Jeong-Hwan Jang, Jae-Ho Lee, Young-Myung Son and Young-Hoon Moon, Effect of Laser Parameters on Sintered Powder Morphology, , Elsevier,(2009),375-378

[7] Majewski, C.E. and Hopkinson, N, Effect of section thickness and build orientation on tensile properties and material characteristics of Laser Sintered nylon-12 parts, Additive Manufacturing Research Group, Loughborough University, Loughborough, United Kingdom, LE11 3TU.422-434

[8] E.O. Olakanmi, R.F. Cochrane, K.W. Dalgarno, A review on selective laser sintering/melting (SLS/SLM) of aluminium alloy powders: Processing, microstructure, and properties, Accepted Manuscript, Progress in Materials Science,AIRJ,2015

a. Manual & Datasheet:

[9] Materials datasheets (properties of CL91RW) visited anddownloaded.pdf, September2014,http://www.femeval.es/proyectos/karma/Documents/D1%202%20Materials%20datasheets%20%208%2010.pdf

[10] IGTR catalogue

[11] www.sciencedirect.com

[12] http://link.springer.com

[13] www.wikipedia.com – The free encyclopaedia